Determination of the Effect of Tension on the Linear Coefficient Of Expansion of Stranded Aluminum Cables

F. G. Heine

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DETERMINATION OF THE EFFECT OF TENSION ON THE LINEAR COEFFICIENT OF EXPANSION OF STRANDED ALUMINUM CABLES.

- - - -

A THESIS PRESENTED BY

F. G. HEINE

TO THE

PRESIDENT AND FACULTY OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE

OF

BACHELOR OF SCIENCE IN ELECTRICAL

ENGINEERING

HAVING COMPLETED THE PRESCRIBED

COURSE OF STUDY

IN

ELECTRICAL ENGINEERING.

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The favorable properties possessed by the metal aluminum, considered electrically, have caused a great demand for it in electrical work. It is now largely used in the manufacture of dynamos and motors, but its greatest field seems to be that of power transmission where it is already successfully competing with copper.

In comparing copper and aluminum, the following facts are of interest:

	Aluminum	Copper
Specific Gravity	2.68	8.93
Relative Specific Gravity	1.00	3.33
Conductivity (Mattheissen Standard Scale)	61 to 63	98 to 99

Tensile strength per sq. in Aluminum 20000 to 35000 lbs.
" " " " " Copper 2 000 to 65000 "

It has been found that for the same conductivity the weight of any 1000 ft. aluminum wire is 47% of the weight of the same length of copper wire. Roughly stated the aluminum wire will have a conductivity twice as great as that of copper wire, weight for weight.

Although the tensile strength of aluminum is less than that of copper, still for cables of the same conductivity the breaking load of the aluminum cable

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is greater than that of the copper cable. It has been found that an aluminum wire with a tensile strength of 31950 lbs. will require the same breaking load as a copper wire of 5[illegible]000 lbs. tensile strength, both wires having the same conductivity. The cost of reducing aluminum from its ores which at one time was so prohibitive has been greatly reduced since the introduction of the Hall process. The above important facts together with the fact that aluminum conductors have stood practical tests on the longest transmission line in the world insure its position in the electrical field.

Since the amount of data on aluminum cables is at present somewhat limited especially as regards transmission line work, the writer thought it advisable to select for a thesis the following subject: "Effect of Tension on the Linear Coefficient of Expansion of Aluminum Stranded Cables."

Since with stranded cables it is desirable to use test pieces of considerable length on account of irregularities in the stranding, a 5[illegible]0000 lb. Riehle Testing Machine was selected for the test as it allowed a cable of about 4[illegible] inches effective length to be supported between its jaws.

the hollow pipe plug were now held in position around this point while a mixture of litharge and glycerine of about the consistency of soft putty was moulded into place, as shown in the illustration, and allowed to harden. On top of the litharge were now poured two layers of pure asphaltum and mineral lac respectively. This junction proved very rigid mechanically and effectively held back the water at the highest temperature.

The accompanying illustration also shows the water jacket in its final state with water outlets and thermometers in place. The thermometers were held in position by perforated corks. The upper end of the water jacket was fitted with a pipe cap through which a hole was drilled large enough to allow the cable to pass freely through it.

With the elastic limit at 12000 lbs. per sq. in. and a cable section of about 408000 circular mils, it was deemed advisable not to allow the tension on the cable to exceed 4000 lbs. in order to avoid undue strain in the solder lugs.

With the safe load thus limited between 0 and about 4000 lbs. the range of motion on the scale beam of the testing machine of the rider [illegible] was very small.

This sample as previously explained, was fitted with water jacket and end lugs. A circulating pump, water heater and rubber tubing completed the circulating system. A cathetometer stand with telescopes was erected on the bed of the machine to observe the deflection. The telescopes were focused upon the edges of sharp red lines on small paper labels pasted near the bottom and top lugs of the cable.

The initial test length of the cable was determined by focusing the telescopes as above stated and then placing a 6 foot wooden engineer's rule in this focus and subtracting the observed readings. The average of several such differences was taken as the initial test length.

The test was begun by raising the temperature of the jacket water to an average of 159.10° Fahr. and subjecting the cable to a load of 1000 lbs. Telescope readings were now taken. The temperature of the jacket water was now lowered by approximately 5° steps and after each change of temperature telescope readings taken, the tension being held constant at 1000 lbs. The test proceeded in this manner down to a temperature of 82 degrees.

The above test was repeated with a constant tension of 3000 lbs. Three independent 3000 lbs. tests were made. A test with a constant tension of 5000 lbs. was attempted. The cable failed; one of the lugs gave out and three strands were ruptured.

The telescope readings were at first tabulated in terms of the number of turns of the micrometer screw head, one turn of the screw head designating a cross hair movement of 0.508 mm. The difference between upper telescope readings and the differences between lower telescope readings were now calculated. These two differences were then subtracted to obtain the total elongation in turns of the number of turns. The results were reduced to millimeters. Dividing each of these results by the corresponding difference in average temperature gave the elongation per degree variation of temperature. This result divided by the initial length of cable yielded the elongation per millimeter per degree variation of temperature or the coefficient of linear expansion. The coefficients were thus calculated for the different tests.

The necessity for this determination will be obvious from the following discussion.

When building a transmission line, it is desirable to know what maximum variations in stress due to variations in temperature will take place in the conductive. Assume the cable to be stretched during the summer at an average temperature of say 80 degrees Fahr. Assume that the lowest temperature to which the cable will be subjected during the winter is say 20° Fahr. The cable will therefore suffer a maximum temperature variation of 60° F. With no tension whatever in the conductor the contraction due to this variation in temperature can easily be calculated from a knowledge of the coefficient of linear expansion. In the case of a transmission line, the cable is under a tension to begin with. The decrease in temperature causes a contraction in the cable. The contraction causes a decrease in sag and therefore a consequent increase in tension. The cable being elastic this increase in tension will necessarily cause an elongation. (1) The contraction and increase in tension may be considered as the direct effects of the temperature variation; (2) The increase in tension being further taken as an independent variable causing an elongation.

Under (1) the question arises as to the effect

of the increasing tension on the coefficient of linear expansion.

It will be seen that these coefficients vary considerably. The general averages however compare favorably with one another and so also do several of the individual determinations. In passing upon the accuracy of these values it must be borne in mind that the test samples experimented upon offer numerous openings to experimental error. The end lugs may have adhered unequally to the various strands. As the cable was little more than 3 feet in length it is doubtful if the percentage difference in length of the different strands between the end lugs was small enough to be neglected. The paper labels being pasted across a number of strands may also have slipped somewhat on account of inequalities in the movement of the strands. Other questions of a similar nature as to physical accuracy might be suggested. Nevertheless, the fact remains that the conditions under which the tests were made approximated closely to those imposed upon the cable when used in transmission line work. Any variations in the values of the coefficients may therefore be safely attributed to experimental error, and the conclusion

drawn that the linear coefficient of expansion of stranded aluminum cable is independent of the tension so long as this tension remains within the elastic limit of the metal.

The knowledge of this fact allows the variations in sags due to temperature changes in a given space of cable to be more easily evaluated. The writer believes that with the aid of 3 simple curves the temperature effect can be determined with sufficient accuracy for all practical purposes. These curves are shown in figs. 1, 2 and 3. The curve shown in fig. 1 is a temperature tension curve and should be determined experimentally. To do this, a piece of cable may be prepared and mounted in a testing machine in an exactly similar manner as previously outlined in the test for effect of tension on the coefficient of expansion. The test will differ from the latter only in that the initial length of the cable is maintained constant by the application of greater tension (assuming the temperature to be decreased). The data obtained will when plotted in the form of a curve show graphically the effect of temperature on the tension. Points for curve shown in fig. 2 may be calculated from a knowledge of the coefficiency of linear expansion. The curve in fig. 3 is the familiar stress strain curve.

Having obtained these curves, their application to transmission line calculations is as follows: Along the ordinate axis of curve 1 lay off the maximum variation in temperature as A-B. From this the consequent variation in tension may be obtained as A'-B' along the X axis. Also lay off the temperature variation along the ordinate axis of curve 2 as B-C and obtain the variation in length as B'-C' along the X axis. Now lay off the tension variation determined from curve 1, along the X axis of curve 3 as D-E and obtain the variation in length due to tension as D'-E' along the ordinate axis. We now have the variation in length due to temperature which may be taken as positive and the variation in length (negative) due to tension. Subtracting these two values we obtain the resultant change in length. Having found the resultant change in length of the cable, the variation in sags may be calculated.

INITIAL LENGTH OF CABLE 996.95 m m

Constant Tension 1000#

Number	Time	Upper Tel.	Lower Tel.	Temperartue T 1.	T2.	T3.
1	2:35	5.374	3.715	159	158.3	160
2	2:48	6.125	5.925	154	152.1	149.5
3	3:05	8.565	6.802	141	140.5	138.0
4	3:17	9.715	7.438	136	127.1	126
5	3:33	10.058	7.530	120.1	114.3	114
6	3:42	10.870	7.470	109	108	109
7	3:59	11.282	7.251	102.5	102	102.4
8	4:20	11.275	7.300	92.1	91.8	92.8
9	4:44	10.994	7.394	81.7	8[illegible].6	83.1

-I- Continued.

No.	Avg. Temp.	Diff. of Temp.	Diff. of Tel. Readings. Upper	Lower
1	159.1			
2	151.86	7.24	0.751	2.210
3	139.83	12.03	2.440	0.877
4	129.70	10.13	1.150	0.636
5	116.13	13.57	0.343	0.092
6	108.66	7.47	0.812	0.060
7	102.3	6.36	0.412	0.219
8	92.23	10.07	0.007	0.049
9	81.80	10.43	0.281	0.094

-I- Continued.

No.	Total Turns Upper Plus Lower	Elong in m m	Elong pr degree fahr.	Elong pr degree m m Co
1	1.459	0.3035	.0419	.00004
2	1.563	0.3251	.0270	.000027
3	.514	.1069	.0105	.0000105
4	.251	0.0271	.002	.000002
5	.752	0.1564	.0209	.000021
6	.193	0.0401	.0063	.0000063
7	.042	0.0087	.00086	.00000086
8	.187	o.0389	.0037	.0000037
			Average	Co.0000126

TENSION 3000# Constant.

No.	Time	Upper Tel.	Lower Tel.	Temperature T1.	T2.	T3.
1	5:04	4.970	-1.847	83.8	92	83
2	5:25	2.040	-4.750	114	118.8	121
3	5:35	1.352	-6.173	124.4	127	129.7
4	5:45	0.248	-6.958	136	137	138.5
5	5:55	minus 0.647	-8.040	143	144	147
6	6:03	minus 1.188	-9.313	148	149.5	152
7	6:18	2.526	-10.920	156	158	158.7

-II- Continued.

No.	Avg. Temp.	Diff of Temp.	Diff of Tel. Readings	
			Upper	Lower
1	82.93			
2	117.93	25.00	2.930	2.903
3	127.03	9.10	0.688	1.423
4	137.60	10.57	1.104	.785
5	144.66	7.06	.895	1.082
6	149.83	5.17	.541	1.273
7	157.56	7.73	1.338	1.607

-II- Continued.

No.	Total Turns Upper plus Lower	Elong in m m	Elong pr degree fahr.	Elong pr degree in m m Co.
1				
2	0.027	.0056	.00022	.0000002
3	0.735	.15288	.0168	.000016
4	.319	.06635	.0062	.0000062
5	.187	,03889	.0055	.0000055
6	.732	.15225	.0294	.000029
7	.269	..1262	.0163	.000016
			Average Co.	.0000125

TENSION CONSTANT 3000#

No.	Time	Upper Tel.	Lower Tel.	Temperature T1.	Temperature T2.	Temperature T3.
1	9:18	4.958	14.704	155	156.5	159
2	9:23	5.768	15.070	149.5	147	147
3	9:26	5.423	14.984	141.5	138.5	140.5
4	9:35	5.406	14.986	133	129	130
5	9:45	6.683	14.460	124	120.5	120.5

-III- Continued.

No.	Avg. Temp.	Diff of Temp.	Diff. of Tel. Readings. Upper	Lower
1	156.83			
2	147.83	9.00	0.810	0.366
3	140.16	7.67	.345	0.086
4	130.66	9.50	.017	0.002
5	121.66	.00	1.277	0.526

-II I- Continued.

No.	Total Turns Upper plus Lower	Elong in m m	Elong per degree fahr.	Elong per degree m m Co.
1				
2	0.444	.09235	.01025	.0000103
3	0.259	.05387	.0070	.0000072
4	0.015	.00312	.00033	.000033
5	0.249	.0518	.0057	.0000057
			Average Co.	.0000655

CONSTANT TENSION 3000#

Initial Length of Cable 1003.3 m m

No.	Time	Upper Tel.	Lower Tel.	Temperature T1.	T2.	T3.
1		7.929	5.599	76.2	76.4	75.5
2		9.840	7.758	98	100	99.5
3		10.108	8.529	113.3	111.2	113.2
4		10.483	10.019	122.5	121.5	122
5		10.500	11.228	129.5	130.5	129.5
6		104.50	115.00	135.5	136.2	135.5
7		12.060	12.322	143.5	144	143.3
8		12.733	13.512	152	152	151.5

-IV- Continued.

No.	Avg. Temp.	Diff of Temp	Diff. of Tel. Readings. Upper	Lower
1	7603			
2	99.16	23.13	1.911	2.159
3	113.56	14.40	0.268	0.771
4	122	8.44	0.375	1.490
5	129.83	7.83	0.017	1.209
6	135.73	5.90	0.050	0.272
7	143.60	7.87	1.610	0.822
8	151.83	8.23	0.673	1.190

-IV- Continued.

No.	Total Turns Upper plus Lower	Elong in m m	Elong pr degree fahr.	Elong pr degree m m Co.
1				
2	0.248	.05158	.0052	.000002
3	0.503	.1046	.00726	.000007
4	1.115	.2320	.0274	.000027
5	1.192	.2479	.0316	.0000031
6	0.222	.0462	.0078	.0000077
7	0.788	.1639	.0258	.0000257
8	0.517	.1075	.01306	.000013
			Average Co.	.00001548

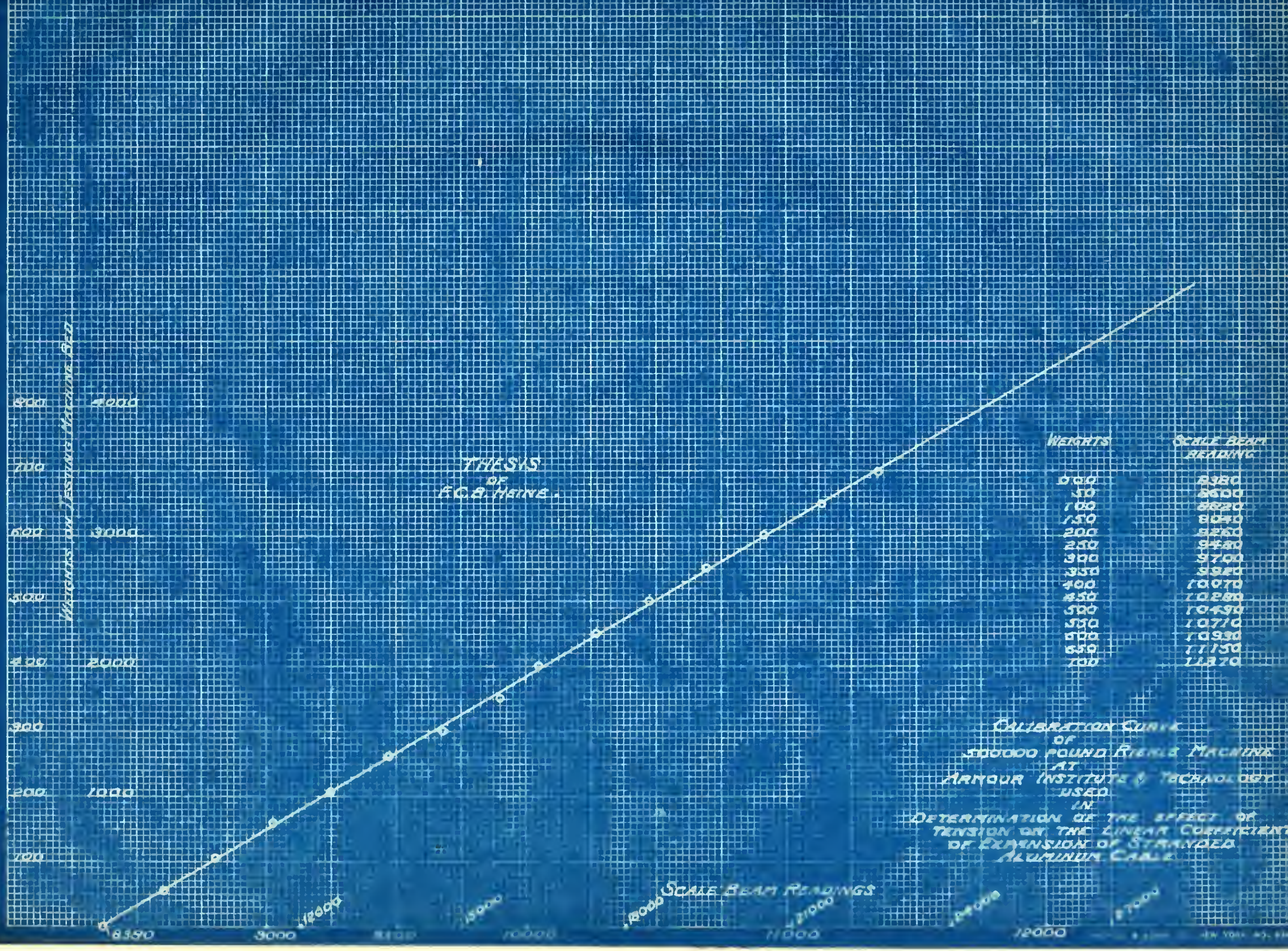
The coefficient of expansion for solid aluminum as given by the Pittsburgh Reduction Co.

= .0000231 per C°. = .0000128 per F°.

No.	Time	Lower	Upper	T2.	T3.
1		[illegible].374	3.715		
2		6.125	5.925		
3	Same	8.565	6.802	Same	Same
4	as	9.715	7.438	as	as
5	for	10.058	7.53	for	for
6	-I-	10.870	7.470	-I-	-I-
7		11.282	7.251		
8		11.275	7.300		
9		10.994	7.394		

No.	Avg. Temp.	Diff of Temp.	Difference of Tel.Readgs. Upper	Lower.
1	159.10	1-5- 42.97	4.684	3.315
2	151.86	2-6 43.20	4.745	1.545
3	139.83	3-7 37.53	2.717	0.449
4	129.70	4-8 37.47	1.560	0.238
5	116.13	5-9 34.33	0.936	.136
6	108.66			
7	102.30			
8	92.23			
9	81.80			

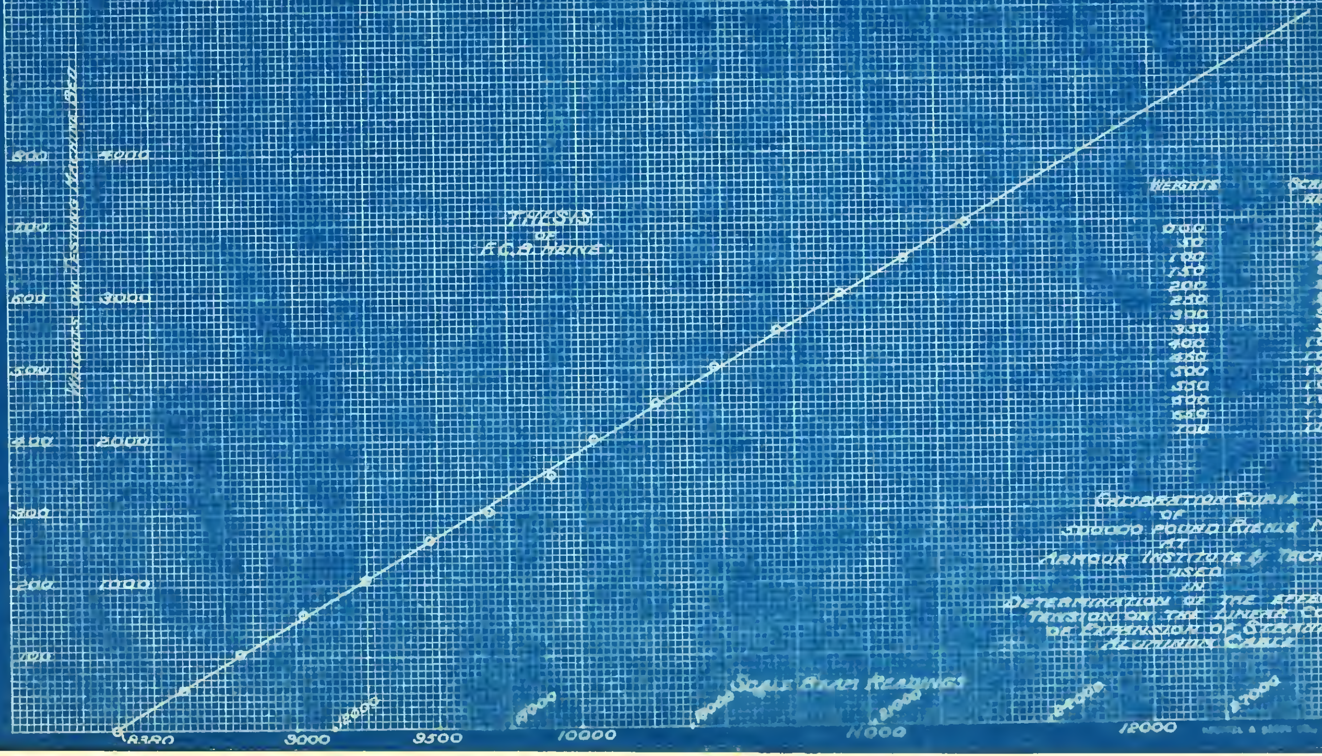
No.	Total Turns Upper plus Lower	Elong. in mm.	Elong. per Degree Fahr.	Elong. per Degree mm.
1	0.769	0.160	.00372	.00000373
2	3.20	.6656	.0154	.0000154
3	2.268	.4717	.01256	.0000126
4	1.322	.27497	.00733	.00000732
5	0.800	.1664	.00484	.00000485
6				
7				
8				
9				
			Average Co.	.00000878



THESIS
OF
F.C.B. HEINE.

WEIGHTS	SCALE BEAM READING
0.00	8380
50	8600
100	8820
150	8040
200	9260
250	9480
300	9700
350	9920
400	10070
450	10280
500	10490
550	10710
600	10930
650	11150
700	11370

CALIBRATION CURVE
OF
300000 POUND RIEHLE MACHINE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
USED
IN
DETERMINATION OF THE EFFECT OF
TENSION ON THE LINEAR COEFFICIENT
OF EXPANSION OF STRANDED
ALUMINUM CABLE

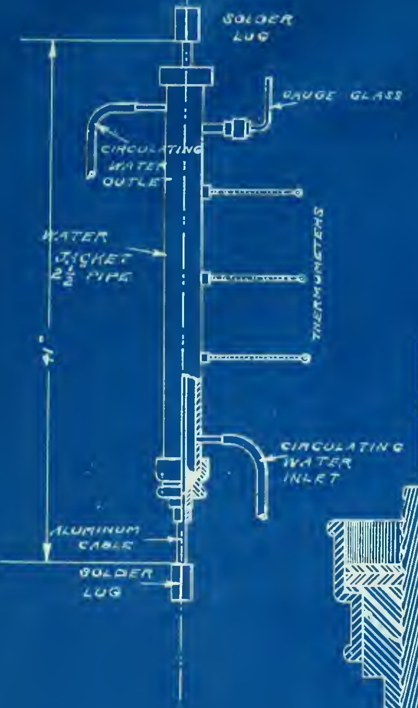


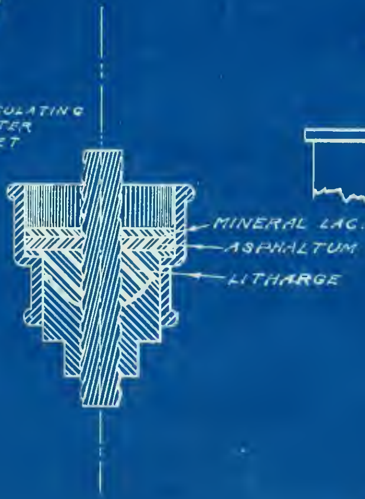
THESIS
OF
F.C.B. HEINS.

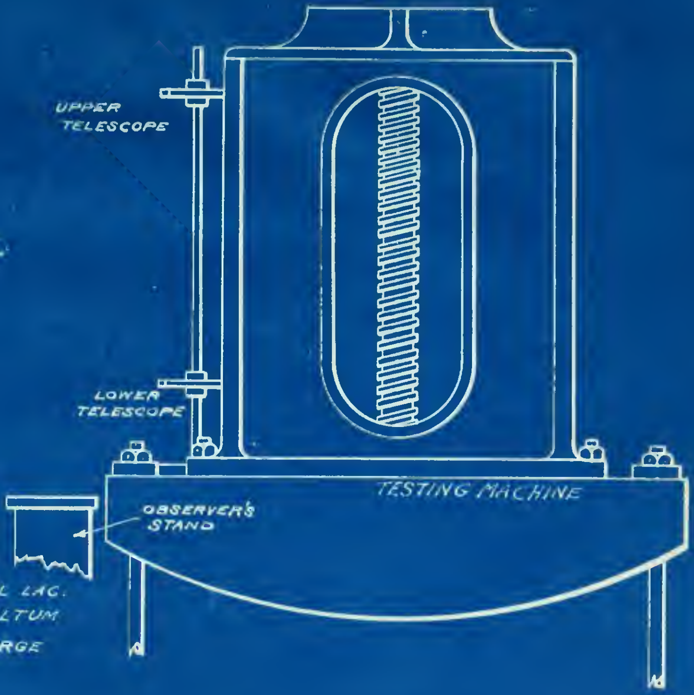
WEIGHTS	SCALE BEAM READING
0.00	8380
50	8600
100	8820
150	9040
200	9260
250	9480
300	9700
350	9920
400	10070
450	10280
500	10490
550	10770
600	10930
650	11150
700	11370

CALIBRATION CURVE
OF
300000 POUND RIEHLE MACHINE
AT
ARMOUR INSTITUTE OF TECHNOLOGY
USED
IN
DETERMINATION OF THE EFFECT OF
TENSION ON THE LINEAR COEFFICIENT
OF EXPANSION OF STRANDED
ALUMINUM CABLE

NEW YORK, NO.







DETAILS OF APPARATUS
USED IN
TEST
ON
DETERMINATION OF THE EFFECT
OF TENSION ON THE LINEAR COEFFICIENT OF
EXPANSION OF STRANDED ALUMINUM CABLE

CURVES
FOR
PREDETERMINATION OF
TEMPERATURE EFFECT
IN
ELECTRIC TRANSMISSION LINES

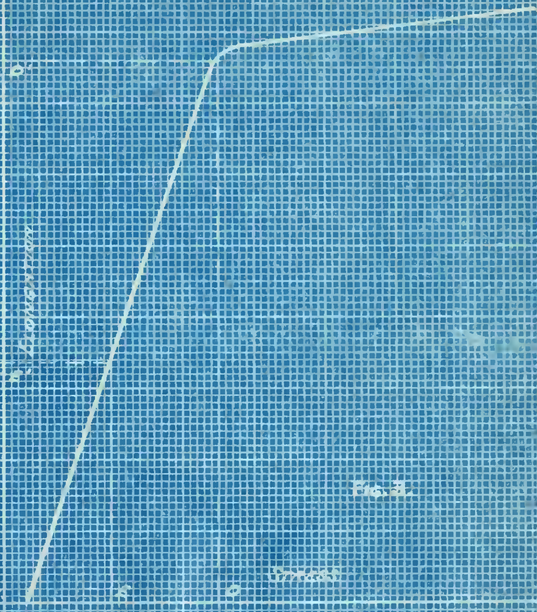


Fig. 3.

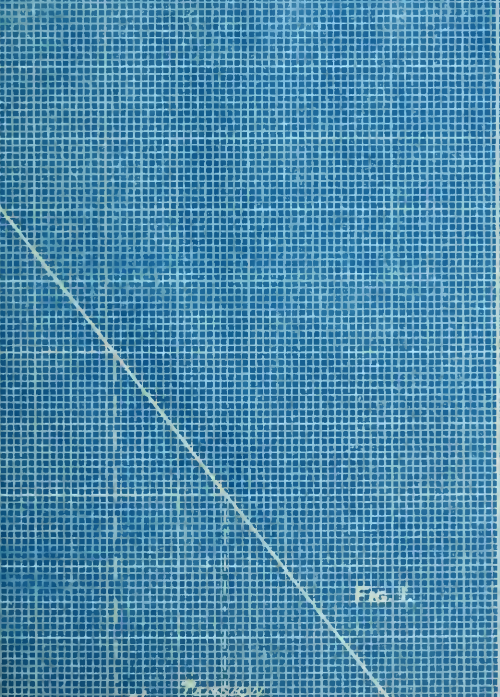


Fig. 1.

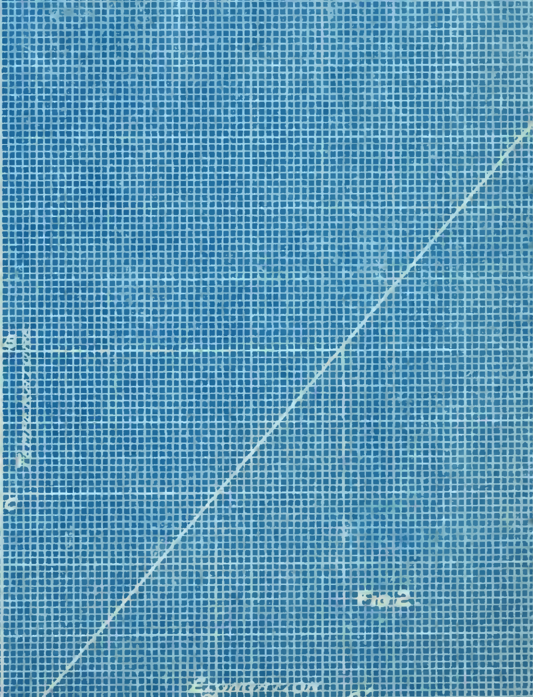
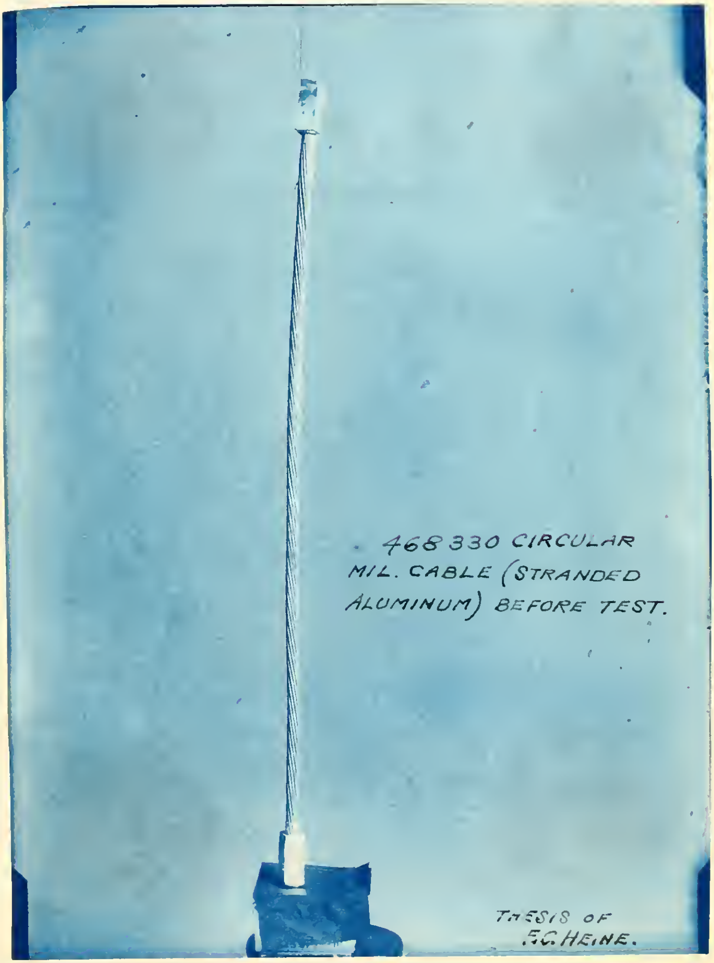


Fig. 2.

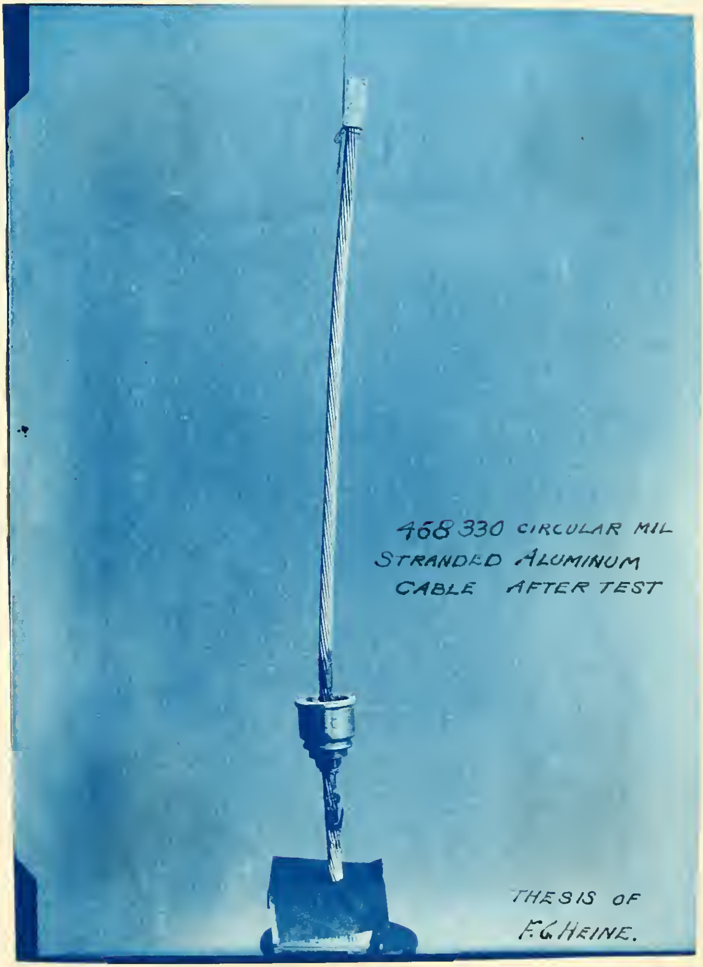
333569 CIRCULAR MIL STRANDED ALUMINUM CABLE.

THESIS OF
F.C. HEINE.



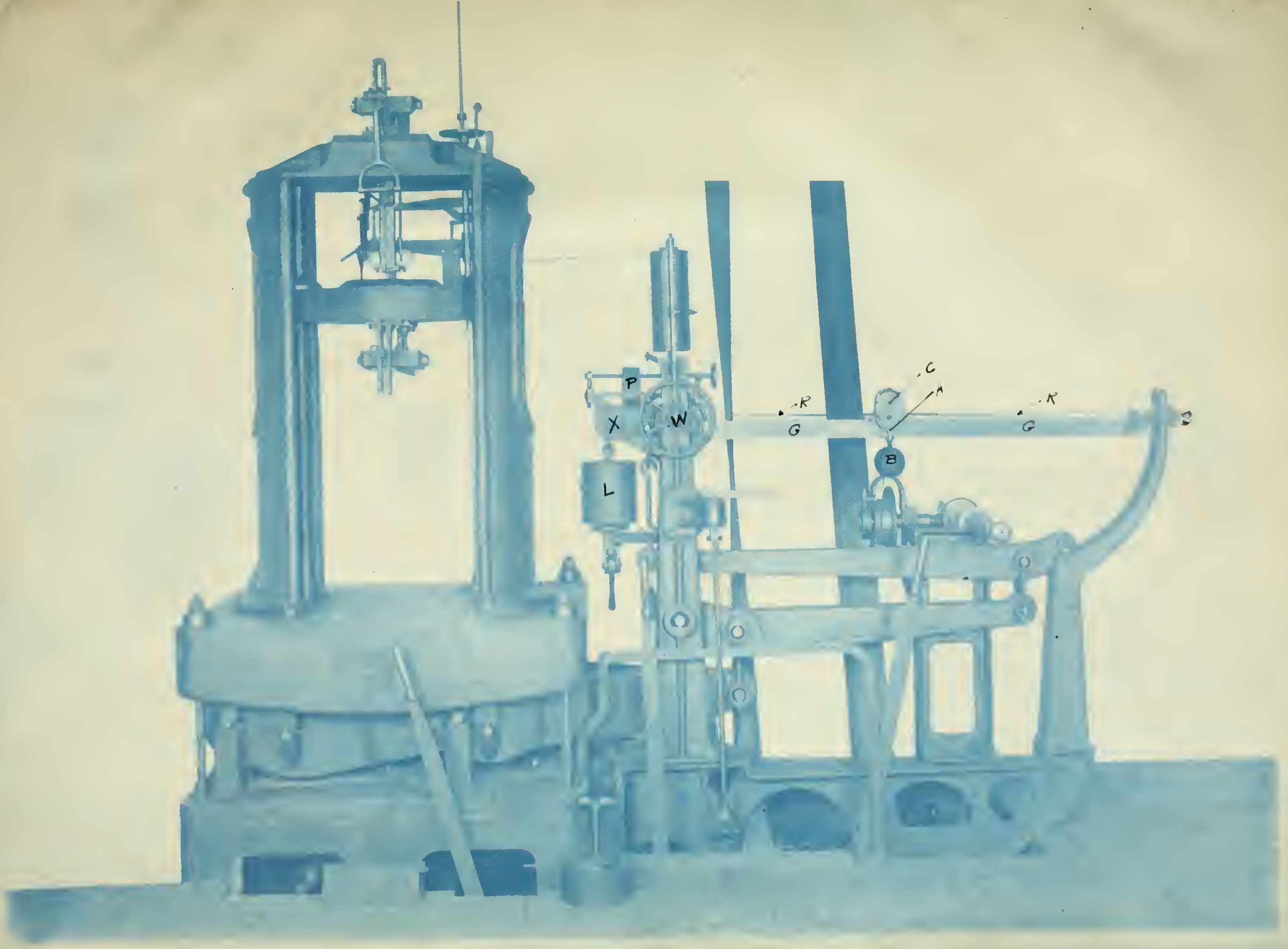
468 330 CIRCULAR MIL. CABLE (STRANDED ALUMINUM) BEFORE TEST.

THESIS OF
F.C. HEINE.



468 330 CIRCULAR MIL
STRANDED ALUMINUM
CABLE AFTER TEST

THESIS OF
F.G. HEINE.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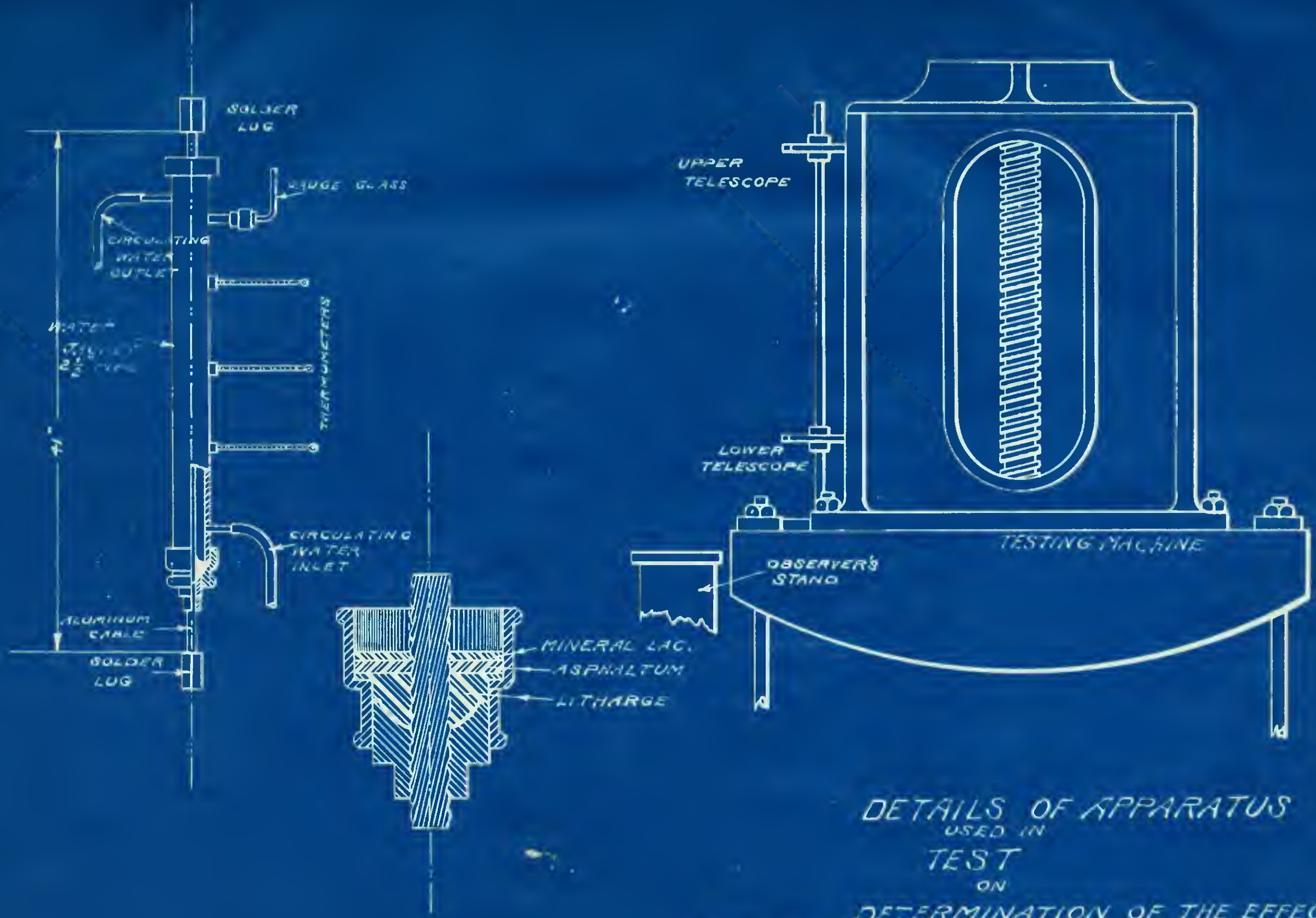

DETAILS OF APPARATUS
USED IN
TEST
ON
DETERMINATION OF THE EFFECT
OF TENSION ON THE LINEAR COEFFICIENT OF
EXPANSION OF STRANDED ALUMINUM CABLE

CURVES FOR PREDETERMINATION OF TEMPERATURE EFFECT IN ELECTRIC TRANSMISSION LINES.

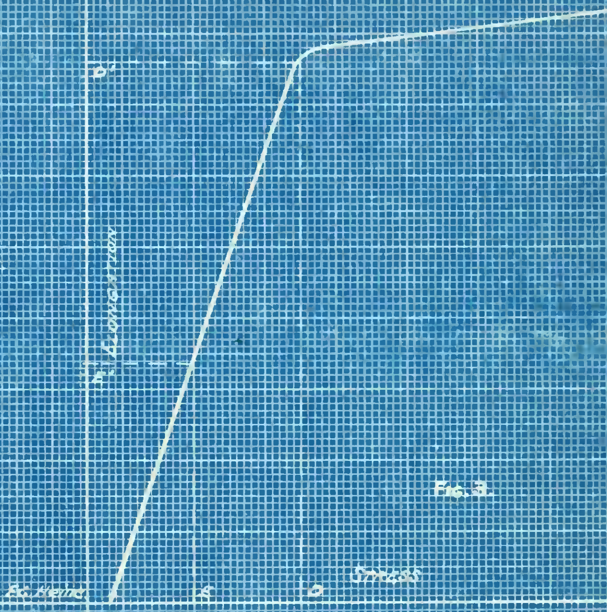

Fig. 3.

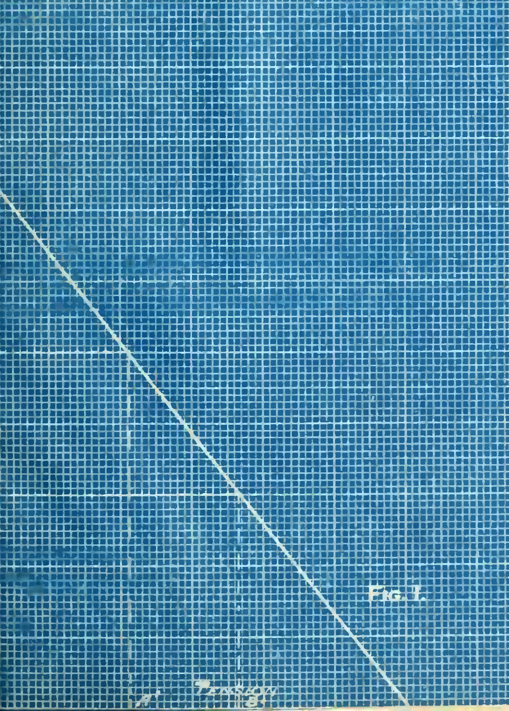

Fig. 1.

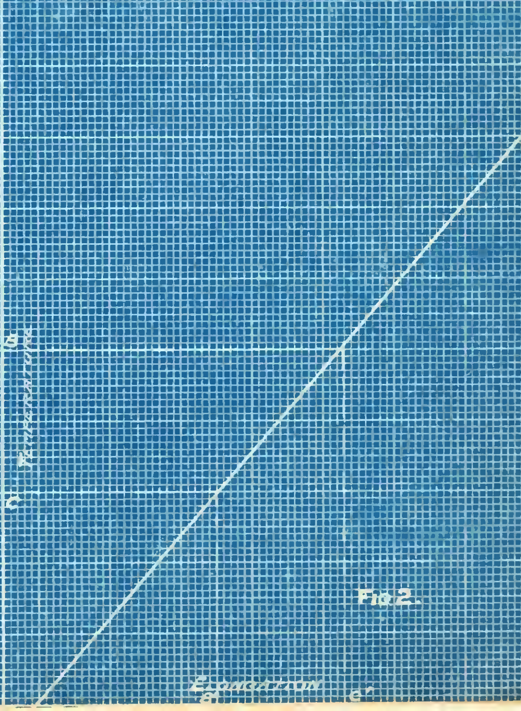

Fig. 2.